BERKELEY LAB
Environment, Health & Safety Division

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Environmental Sampling Project Task Force

Dear Task Force Members:

At the August 10, 2000 meeting of the LBNL Environmental Sampling Project Task Force, Dr. Owen Hoffman of SENES Oak Ridge, Inc. presented calculations made in response to an issue raised by IFEU in its initial report to the City of Berkeley. IFEU had raised the issue of potential doses from discrete releases of tritium from the National Tritium Labelling Facility (NTLF).

In response to Dr. Hoffman's presentation, a Task Force member raised a concern related to the dose that a Lawrence Hall of Science (LHS) worker could receive from cumulative NTLF releases. The attached report, dated October 27, 2000 and entitled "The Assessment of Radiological Dose and Excess Lifetime Risk of Cancer for an Employee of the Lawrence Hall of Science Exposed to Future Releases of Tritiated Water Vapor from Routine Operation of the National Tritium Labelling Facility at Lawrence Berkeley National Laboratory," addresses this concern.

This assessment calculates the additional risk (above natural background radiation) for a full-time employee who works at the LHS for 30 years. It uses the most recent uncertainty information for estimating cancer incidence due to exposure to ionizing radiation at low dose rates. The calculation indicates an additional risk above background for the LHS employee that ranges from approximately 0.05 to 2.5 chances in one million. This additional risk is indistinguishable from zero. It should be noted that the lifetime risk of cancer for individuals in the San Francisco Bay Area is approximately one in three.

IFEU also criticized the use of another model called CAP88PC at the Lab site because it doesn't adjust for changes in terrain and for puff releases. This EPA-approved model is mandated by EPA regulations for compliance purposes at our site. The CALPUFF model was chosen in this case because it can adjust for changes in terrain and for puff releases, and because this assessment was not for compliance purposes. The SENES report also concludes that projected doses from the CALPUFF model are very small, far below the EPA regulatory limit of 10 millirem per year. This conclusion is consistent with the CAP88PC modeled results.

Dr. Hoffman will be attending the next Task Force meeting and will be available to answer any questions about this assessment.

Sincerely,

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The Assessment of Radiological Dose and Excess Lifetime Risk of Cancer for an Employee of the Lawrence Hall of Science Exposed to Future Releases of Tritiated Water Vapor from Routine Operation of the National Tritium Labelling Facility at Lawrence Berkeley National Laboratory

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INTRODUCTION

This assessment evaluates the radiation dose and excess lifetime risk of cancer incidence to an employee of the Lawrence Hall of Science (LHS) as a result of exposure to future releases of tritiated water vapor (HTO) from routine operation of the National Tritium Labelling Facility (NTLF) at the Lawrence Berkeley National Laboratory (LBNL). A meteorological model that is appropriate for complex terrain and near-field transport (CALPUFF; Scire et al., 1999) has been applied to this assessment.

This report summarizes a risk assessment performed independently by SENES Oak Ridge, Inc. for long-term emissions of HTO from the NTLF using the CALPUFF dispersion modeling system (calibrated for the LBNL site) and the most recent information on the uncertainty in estimating the exposure and excess lifetime risk of cancer incidence due to exposure to ionizing radiation at low dose rates. The general methodology used in this assessment is presented in Thomas and Hoffman (2000).

Figure 1 illustrates the location of the LHS and the Building 75 hillside stack (point of HTO release), as well as the daytime wind flow patterns.

ASSUMPTIONS AND INPUTS

This assessment estimates the dose and risk for an employee working at the LHS for periods of 10, 20 or 30 years, beginning at age 20. It is assumed that the LHS employee will potentially be exposed for 9 hours per day, 5 days per week, for 52 weeks (2,340 hours/year), minus vacation, holidays and sick-leave (approximately 33 days/year). Therefore, it is assumed that the employee spends 2043 work-day hours per year at the LHS.

Measurements of annual routine HTO emissions for the years 1997-1999 have been used to estimate a future long-term average release amount of HTO. The annual routine releases of HTO from the Building 75 hillside stack for 1997, 1998, and 1999 were 24 Ci (890 GBq), 40 Ci (1500 GBq), and 17 Ci (630 GBq), respectively (LBNL, 1998, 1999, 2000). The annual average amount of HTO released during the three year period was 27 Ci (1,000 GBq).

For the present assessment, it is assumed that the NTLF will continue operating in a similar manner for the next thirty years (i.e., there will be no significant modifications in operating procedure or improvements to the tritium labeling protocols or emission abatement technology). Therefore, the annual average stack release of 27 Ci (1,000 GBq) is assumed to be representative for each year and carried out for the next 30 years.

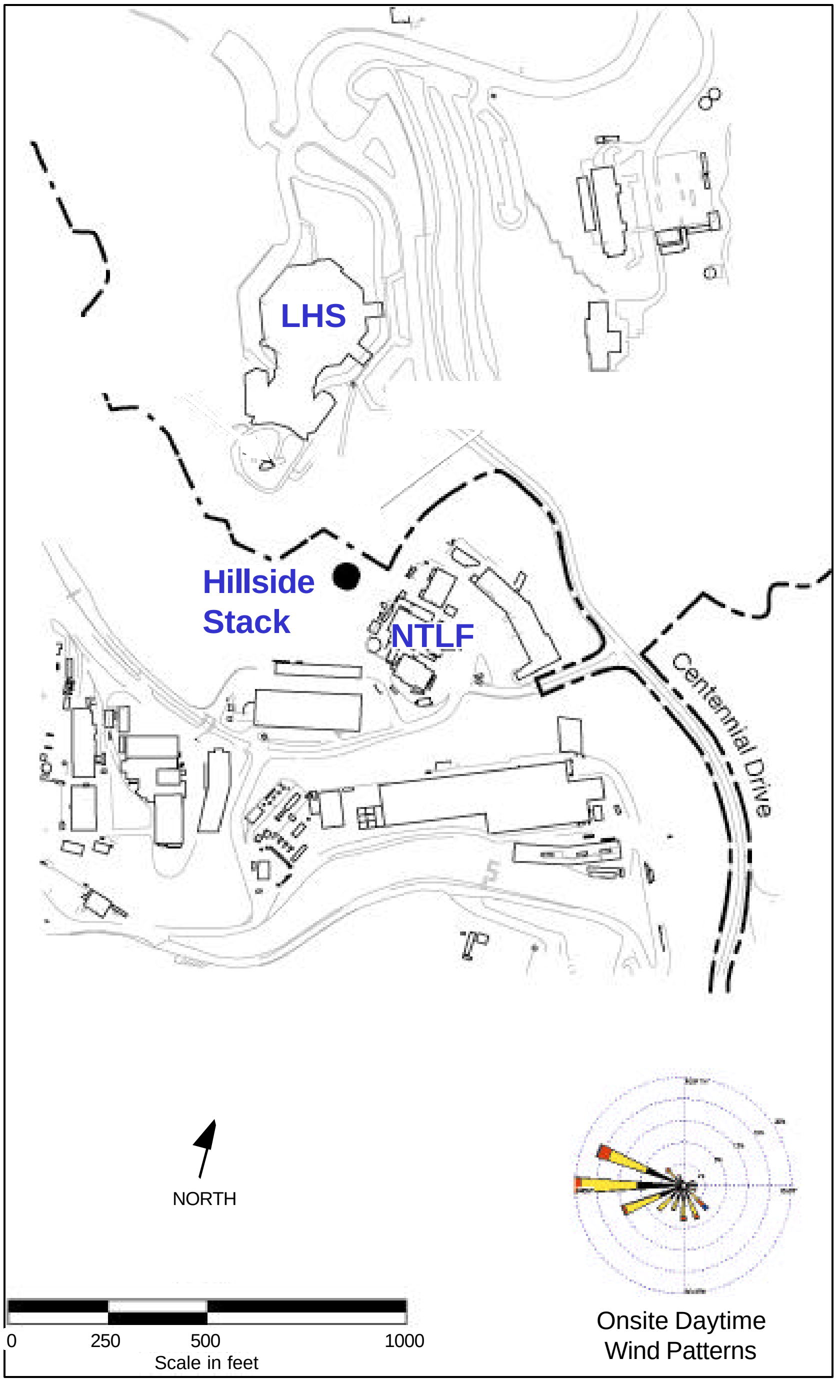

Figure 1. Map of receptors and source locations. A wind rose describing general onsite daytime wind patterns is also included (the wind rose shows the frequency of directions from which the wind blows).

In this assessment, daytime meteorology is matched with daytime HTO emissions. Accordingly, annual average HTO emissions during daytime hours (8 am to 6 pm) were calculated to be 11 Ci (407 GBq) (10/24ths of 27 Ci). Although an LHS employee is only assumed to be present for 9 hours per day, five days per week, meteorology and emissions are considered for all daytime hours (10 hours per day, 7 days per week). Uncertainty in the individual annual average emissions over the assessment period was characterized by a lognormal distribution with a median of 11 Ci and a geometric standard deviation of 1.39. These characteristics define a 95% uncertainty range of 5.7 to 21 Ci (210 to 780 GBq). In other words, over a 30-year period of time, the average annual daytime release of HTO from the source is estimated to be larger than 5.7 Ci per year but less than 21 Ci per year.

The indoor air tritium concentration at the LHS is assumed to be equivalent to those calculated for the southern patio of the LHS. The intake of HTO into the body is assumed to occur primarily from inhalation and skin absorption. The breathing rates used in this analysis (Table 1) are based on studies presented in EPA's Exposure Factors Handbook (EPA, 1997). The most recent age-dependent dose coefficients from the International Commission on Radiological Protection (ICRP, 1998) were used to estimate doses to each individual organ, given the age and gender of the representative LHS employee.

Table 1. Summary of Input Parameters used in this Assessment

Parameter	**Uncertainty distribution**	**Source**
Annual average release of HTO (Ci)	Lognormal (11[a], 1.39)[b]	Measurements[c]
Fraction of daytime hrs that exposure occurs	(2043/3650) = 0.56	
Breathing rate (m^3/h)		
Male, adult	Triangular (1.0, 1.4, 1.8)[d]	EPA, 1997
Female, adult	Triangular (0.9, 1.3, 1.7)	EPA, 1997
Dose conversion factor (Sv/Bq)		
Age 35	Lognormal (1.8×10^{-11}, 1.4)	ICRP, 1998
Relative biological effectiveness for tritium	Logtriangular (1, 2, 5)[e]	Straume, 1993, 1998 and personal communication

a 11 Ci = 407 GBq
b Lognormal (geometric mean, geometric standard deviation)
c HTO released per year between the hours of 8 am and 6 pm, 7 days per week (LBNL, 1998; LBNL, 1999; LBNL, 2000).
d Triangular (minimum, median, maximum)
e Logtriangular (minimum, median, maximum)

Relative biological effectiveness (RBE) represents the difference in the amount of biological damage caused by different types or sources of radiation. The RBE is defined as the ratio of the absorbed dose of a reference type of radiation producing a certain kind and degree of biological effect to the absorbed dose of the radiation under consideration required to produce the same kind and degree of effect. The Health Physics literature indicates that RBE values for tritium beta rays may be higher than the value of one generally assumed for evaluating compliance with regulatory dose limits (Straume, 2000; Straume, 1998; Straume, 1993). In the present assessment, a logtriangular distribution of alternative values of RBE for tritium was used ranging from 1.0 to 5.0 with a mode at 2.0. This distribution reflects the uncertainty in the RBE for tritium.

The values of excess lifetime risk of cancer incidence per unit dose used in this assessment have been derived from estimates of the excess relative risk per unit dose (ERR per Sv) developed with the National Cancer Institute in updating the 1985 Radioepidemiological Tables (Land, 2000). The values of excess lifetime risk of cancer incidence per unit equivalent organ dose are the product of the ERR per Sv and the background incidence rate of reported cancers for the San Francisco Bay Area (Parkin et al., 1997). The values of ERR per Sv used in this study are currently under review by a National Academy of Sciences panel.

The risk estimates used for this assessment are specific for exposures at low doses and low dose rates. The reduced effectiveness of radiation exposure at low doses and low dose rates applies directly to the assessment of long term chronic exposure to HTO. The amount of reduced effectiveness is, however, uncertain ranging from 1.0 (no reduction) to 5.0 (a reduction that is five times less than for the same dose delivered at a high dose rate). However, no credit is given to the likelihood of the existence of a threshold dose below which the risk is zero. This assumption is consistent with uncertainty analyses performed on the radiogenic cancer risk by NCRP (1997) and EPA (1999).

SUMMARY OF RESULTS

A summary of doses and excess lifetime risks of cancer incidence are summarized in Table 2. Table 2 also provides the 95% uncertainty range for the estimated intake of HTO, the equivalent dose, and excess lifetime risk of cancer incidence.

The projected 30-year annual average amount of HTO released from the Building 75 hillside stack ranges from 5.7 to 21 Ci (210 to 780 GBq; 95% uncertainty range), with a median of 11 Ci (410 GBq). The time-integrated air concentration for the daytime hours at the LHS (10 hrs per day; 365 days per year; 30 years) ranges from 1.9×10^4 to 2.0×10^5 Bq h/m^3, with a central value (median) of 5.9×10^4 Bq h/m^3. These time-integrated concentrations were determined by dispersion modeling using CALPUFF.

The intake of tritium by an LHS employee was calculated by multiplying the time-integrated air concentration at the LHS (for a 10-hour day) with the breathing rate of the individual and the frequency of exposure (fraction of daytime hours that an individual is present at the LHS).

The RBE-adjusted whole-body dose for tritium is estimated by multiplying the intake by the dose conversion factor presented in Table 1. The annual dose rate per year that a male would receive ranges (95% uncertainty range) from 0.0022 to 0.042 mrem/yr (0.022 to 0.42 μSv/yr) with a median of 0.0093 mrem/yr (0.093 μSv). The dose for females is not substantially different from that of males (Table 2). The total cumulative tritium dose for males employed at the LHS for 30 years ranges (95% uncertainty range) from 0.06 to 1.3 mrem (0.6 to 13 μSv) with a median of 0.29 mrem (2.9 μSv).

The 95% uncertainty range of excess lifetime risk of cancer incidence for a male working at the LHS for 30 years, beginning at age 20, is 0.046 to 1.7 chances in one million, with a central estimate of 0.26 chances in one million. The 95% uncertainty range of excess lifetime risk for a female working at the LHS for 30 years, beginning at age 20, is 0.051 to 2.5 chances in one million, with a central estimate of 0.34 chances in one million.

Table 2. Results for an individual working for 30 years at the Lawrence Hall of Science.

		Male			Female		
		95% uncertainty range			95% uncertainty range		
	units	lower	central	upper	lower	central	upper
Annual average release amount (HTO)	Ci (GBq)	5.7 (210)	11 (410)	21 (780)	5.7 (210)	11 (410)	21 (780)
χ / Q[a]	s/m^3	7.1×10^{-6}	1.8×10^{-5}	4.5×10^{-5}	7.1×10^{-6}	1.8×10^{-5}	4.5×10^{-5}
Air concentration	Bq/m^3	0.18	0.54	1.8	0.18	0.54	1.8
Time integrated air concentration[b]	Bq h/m^3	1.9×10^4	5.9×10^4	2.0×10^5	1.1×10^4	3.4×10^4	1.0×10^5
Total number of hours exposed	h	---	61,200	---	---	61,200	---
Inhalation rate	m^3/h	1.1	1.4	1.7	0.99	1.3	1.6
Intake from inhalation	Bq	13000	47000	150000	13000	45000	140000
Intake from skin absorption	Bq	3400	14000	54000	3400	14000	54000
Total intake[c]	Bq	17000	63000	200000	17000	60000	200000
Dose conversion factor (ICRP)	Sv/Bq	9.4×10^{-12}	1.8×10^{-11}	3.5×10^{-11}	9.4×10^{-12}	1.8×10^{-11}	3.5×10^{-11}
RBE for tritium	unitless	1.3	2.6	4.4	1.3	2.6	4.4
Maximum annual dose rate	mrem/yr (µSv/yr)	0.0022 (0.022)	0.0093 (0.093)	0.042 (0.42)	0.0021 (0.021)	0.0089 (0.089)	0.039 (0.39)
Total cumulative dose[d]	mrem (µSv)	0.060 (0.60)	0.29 (2.9)	1.3 13)	0.062 (0.62)	0.27 (2.7)	1.3 (13)
Risk per unit dose	Risk/mrem (Risk/µSv)	3.0×10^{-7} (3.0×10^{-6})	9.6×10^{-7} (9.6×10^{-6})	3.1×10^{-6} (3.1×10^{-5})	4.3×10^{-7} (4.3×10^{-6})	1.3×10^{-6} (1.3×10^{-5})	4.0×10^{-6} (4.0×10^{-5})
Excess Lifetime Risk[d]		$\mathbf{4.6 \times 10^{-8}}$	$\mathbf{2.6 \times 10^{-7}}$	$\mathbf{1.7 \times 10^{-6}}$	$\mathbf{5.1 \times 10^{-8}}$	$\mathbf{3.4 \times 10^{-7}}$	$\mathbf{2.5 \times 10^{-6}}$
Chances in 1 million		0.046	0.26	1.7	0.051	0.34	2.5

[a] The χ / Q (chi over q) is representative of atmospheric dispersion and is defined as the concentration in air (χ) for a unit release (Q).

[b] The time integrated air concentration (Bq/h m^3) is a result of multiplying the CALPUFF-generated air concentration (Bq/m^3) by the number of daytime hours (10 hours) per year (3650 hrs for 30 years = 109,500 hrs).

[c] All calculations have been performed using Monte Carlo error propagation techniques; therefore, results are not directly additive.

[d] Based on a 30 year occupational exposure.

In addition to presenting the excess lifetime risk of cancer incidence for an individual employed by the LHS for 30 years, this assessment also estimates risks for 10 and 20 year employment histories. These risks are presented in Table 3.

Table 3. Excess lifetime risk of cancer incidence as a function of the number of years that an individual is employed at the LHS.

	Male			Female		
Years of	95% uncertainty range			95% uncertainty range		
Employment	lower	central	upper	lower	central	upper
10	1.6×10^{-8} (0.016)[a]	8.5×10^{-8} (0.085)	5.3×10^{-7} (0.53)	1.8×10^{-8} (0.018)	1.1×10^{-7} (0.11)	7.6×10^{-7} (0.76)
20	3.1×10^{-8} (0.031)	1.7×10^{-7} (0.17)	1.1×10^{-6} (1.1)	3.6×10^{-8} (0.036)	2.2×10^{-7} (0.22)	1.5×10^{-6} (1.5)
30	4.6×10^{-8} (0.046)	2.6×10^{-7} (0.26)	1.7×10^{-6} (1.7)	5.1×10^{-8} (0.051)	3.4×10^{-7} (0.34)	2.5×10^{-6} (2.5)

[a] The values in parentheses represent chances in one million.

UNCERTAINTY ANALYSIS OF INPUTS AND ASSUMPTIONS

An analysis was performed to identify which input parameters and assumptions contributed the most to the uncertainty range of the excess lifetime risk estimate for each scenario. These results are presented in Table 4. For this assessment, the primary contributors to the overall uncertainty were the estimated air concentration of HTO at the LHS and the excess risk per unit dose. For this scenario, the uncertainties associated with the breathing rate and the body surface area are negligible.

Table 4. Relative contribution of input parameters to the total uncertainty in the excess lifetime risk of cancer incidence.

	Contribution to total uncertainty in risk (%)	
Uncertain Parameter	male	female
Air concentration[a]	38.0	38.6
Breathing rate	0.2	1.1
Body surface area	0.7	0.9
Dose conversion factor	9.7	9.6
RBE for HTO	11.5	12.6
Risk per unit dose[b]	39.8	37.3

[a] The uncertainty in the air concentration is composed of 67% due to the uncertainty in the meteorological dispersion and 33% due to the uncertainty associated with the projected tritium released (33%).

[b] The primary contributors of uncertainty in the risk per unit dose are the dose and dose rate effectiveness factor and the original excess relative risk per Sv obtained from data on the Japanese survivors of the bombings of Hiroshima and Nagasaki. These two factors make up approximately 65% of the uncertainty in the risk per unit dose (Land, 2000).

The uncertainty in the estimated air concentration is made up of the uncertainty in the projected amount of tritium released and the estimate of atmospheric dispersion averaged over long time periods which, in turn, is dependent on wind trajectory, wind speed, and atmospheric stability at the time of the release. The uncertainty in the risk per unit dose factors is primarily due to uncertainty in the original excess relative risk per Sv obtained from the Lifetime Survivor Study of the Japanese population that survived the atomic bombing of Hiroshima and Nagasaki (Land et al., 2000) and to the dose and dose rate effectiveness factor (DDREF). The DDREF is applied to extrapolate the dose response relationship from effects observed at high doses to low doses and from effects observed at high dose rates to those manifested at low dose rates (acute vs. chronic exposures).

The specific cancer types that makeup the total excess lifetime risk of cancer incidence are listed in Table 5. This table shows that the lung cancer, colon cancer, and cancer of urinary organs are important for both males and females, with liver and prostate cancer being additionally important for males and breast cancer being important for females. The importance of a given cancer type is determined by both the magnitude of the excess relative risk per unit dose obtained from the most recent epidemiological studies of the Japanese A-bomb survivors and the magnitude of the background incidence of disease for the San Francisco Bay region.

Table 5. Contribution of specific cancer types to the total excess lifetime risk of cancer incidence.

Male		**Female**	
Cancer type	Contribution (%)	Cancer type	Contribution (%)
Lung	21.5	Lung	30.2
Colon	16.9	Urinary organs	24.2
Urinary organs	13.8	Breast	16.7
Liver	7.7	Colon	8.7
Prostate	7.6	Ovary	2.7
Remainder	32.5	Remainder	17.5

CONCLUSIONS

This assessment estimated the dose and excess lifetime risk of cancer incidence to a worker at the Lawrence Hall of Science from a 10, 20 or 30 year exposure to tritium (HTO) released from the Hillside stack of the NTLF. The resultant dose and risk estimates support conclusions from previous Berkeley Lab reports (i.e., Site Environmental Reports; LBNL 1998, 1999, 2000) indicating that off-site exposures, doses, and health risks from NTLF releases are very low.

For example, using the 95% uncertainty range, the maximum annual dose from HTO to the whole body of an LHS worker is estimated to be approximately 0.002 to 0.04 mrem/yr (0.02 to 0.4 μSv/yr). This range is far below the NESHAP standard of 10 mrem/yr (100 μSv/yr). Extrapolating this exposure for a 30-year period, the cumulative whole body dose under the same set of assumptions ranges from 0.06 to 1.3 mrem (0.6 to 13 μSv). This cumulative dose is below the total acute dose that is required to detect an excess risk in a very large population of exposed individuals (1,000 to 30,000 mrem, or 10,000 to 300,000 μSv).

The doses calculated in this assessment are small incremental fractions above the dose received from natural background radiation. For example, the whole body dose from background radiation (excluding exposure to indoor radon) is equivalent to about 100 mrem/yr (1,000 μSv/yr) or 3,000 mrem in 30 years (30,000 μSv).

The lifetime risk of cancer incidence for individuals in the San Francisco Bay area who were not exposed to HTO from NTLF operations is approximately one in three. This assessment calculated the incremental risk above background for a 30-year exposure to a worker at the Lawrence Hall of Science using the most current information available on radiogenic cancer risks. This risk ranges from approximately 0.05 to 2.5 chances in one million. This small incremental risk above background would be indistinguishable from zero. Because of this small risk value and the small number of individuals who might work at the LHS for the entire assumed duration of thirty years, no additional excess cases of cancer would be expected due to exposure to tritium releases from the NTLF.

REFERENCES

EPA (Environmental Protection Agency). 1997. Exposure Factors Handbook – Volume I. Office of Research and Development. Washington, D.C. EPA/600/P-95/002Fa.

EPA (Environmental Protection Agency). 1999. Estimating Radiogenic Cancer Risks; Addendum: Uncertainty Analysis. Air and Radiation. EPA 402-R-99-003. May.

ICRP (International Commission on Radiological Protection). 1998. The ICRP Database of Dose Coefficients: Workers and Members of the Public. Version 1.0. Elsevier Science Ltd. ISBN 0 08 042 7510.

Land, C. (chairman). 2000. Draft Report of the NCI-CDC Working Group to Revise the 1985 NIH Radioepidemiological Tables. National Cancer Institute.

LBNL, 1998. Site Environmental Report for 1997. Volume II. LBNL-27170. . Ernest Orlando Lawrence Berkeley National Laboratory. September 1998.

LBNL, 1999. Site Environmental Report for 1998. Volume II. LBNL-27170. Ernest Orlando Lawrence Berkeley National Laboratory. September 1999.

LBNL, 2000. Site Environmental Report for 1999. Volume II. LBNL-27170. Ernest Orlando Lawrence Berkeley National Laboratory. September 2000.

NCRP (National Council on Radiation Protection and Measurements). 1997. Uncertainty in Fatal Cancer Risk Estimates Used in Radiation Protection. NCRP Publication No. 126.

Parkin, D.M., Whelan, S.L., Ferlay, R.L., Young, J. (eds.). 1997. Cancer Incidence in five Continents, Vol VII (IARC Scientific Publications No. 143).

Scire, J.S., Strimaitis G.D., and Yamartino, R.J. 1999. A User's Guide for the CALPUFF Meteorological Dispersion Model (Version 5.0). Earth Tech, Inc. October.

Straume, T. 1993. Tritium Radiobiology and Relative Biological Effectiveness. Health Physics. Volume 65. Number 6. Pages 657-672.

Straume, T. 1998. Review of "Environmental Health-Risk Assessment for Tritium Releases at the National Tritium Labeling Facility at Lawrence Berkeley National Laboratory, LBL-37760/UC-2000, April 1997". February 3, 1998.

Straume, T. 2000. Personal communication with Owen Hoffman. May 2000.

Thomas, B., Hoffman, O. 2000. The Estimate of Excess Lifetime Risk of Cancer Incidence Associated with Discrete Routine Releases of Tritiated Water Vapor (HTO) from the National Tritium Labelling Facility at Lawrence Berkeley National Laboratory. September 13, 2000. SOR/TR-003-900.